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GUIDE TO THE GRADING OF STRUCTURAL TIMBERS AND THE DETERMINATION OF WORKING STRESSES

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INTRODUCTION

The authorized program of research in forest products carried on by the Forest Products Laboratory, Forest Service, United States Department of Agriculture, has for many years included studies of the strength and grading of structural timbers.

Because of variations in such features as the quality of the wood, the number and sizes of knots, the degree of cross grain, and the extent of shakes and checks, one timber of a species may be several times as strong as another. Hence, without classification of timbers, design stresses must be adapted to the strength of the poorer pieces of each species. If, however, timbers of each species are classified into groups

[1] Credit is due J. A. Newlin, in charge, Section of Timber Mechanics, Forest Products Laboratory, for important contributions to the development and application of engineering principles in the grading of timber. Credit in this connection is due also to members of the committee on timber, American Society for Testing Materials, and of the committee on wooden bridges and trestles, American Railway Engineering Association, and to representatives of various lumber companies and associations. The author acknowledges helpful suggestions received from various members of the staff of the Forest Products Laboratory and from others who have reviewed the manuscript of this circular.

[2] Maintained by the U.S. Department of Agriculture at Madison, Wis., in cooperation with the University of Wisconsin.

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or grades on the basis of the features that affect strength, the strengths of the poorer pieces admitted in each grade become the minimums to be considered. Consequently, grading promotes economy and dependability in the use of timber as a structural material.

The principles of grading timbers for strength were presented in United States Department of Agriculture Circular 295 (*5*)[3] together with descriptions of four proposed basic grades each of which is of a different standard of strength. Provisions based on these principles were included in American lumber standards, Simplified Practice Recommendation R16-29 (*8*) and illustrated by descriptions of two grade examples. Neither publication shows how to describe other grades or to determine appropriate working stresses.

This circular presents a generalized system for specifying the features that affect the strength of timbers together with a procedure for determining the working stresses appropriate to any grade. With the help of the data given here, individual pieces or lots of timber can be graded by the user or distributor, grade descriptions can be prepared by the lumber manufacturer or user, and working stresses for grades described in lumber association rules or elsewhere can be determined or checked by the engineer, architect, or contractor. The system presented is based on the same principles of grading as are the two publications cited but because of additional features, it is of much wider application.

Part 1 presents grade descriptions "in blank." Only paragraphs relating to features that affect strength are included. Part 2 supplies data to fill the blanks and make the descriptions applicable to grades having strength ratios as desired. Details in which part 1 differs from American lumber standards are indicated by italics and are commented on in footnotes. Part 3 discusses topics related to grading for strength. Part 4 shows how to determine the working stress appropriate to a grade, and part 5 evaluates existing commercial grades.

PART 1. SPECIFICATION REQUIREMENTS FOR STRENGTH GRADES

A. CLASSIFICATION

The effects of knots, deviations of grain, shakes, and checks on the strength of a timber vary with the loading to which the piece is subjected. Also the effect of seasoning varies with the size of the timber. Consequently, efficiency in grading necessitates classifying timbers according to their size and use. Specifications as presented herein are for three classes as follows:

1. Beams and stringers. Pieces of rectangular cross section, 5 by 8 inches and up, graded with respect to their strength as beams when loaded on the narrow face.
2. Joist and plank. Pieces of rectangular cross section, 2 to 4 inches in thickness by 4 inches and wider, graded with respect to their strength as beams when loaded either on the narrow face as joist or on the wide face as plank.
3. Posts and timbers. Pieces of square or approximately square square cross sections, 4 by 4 inches and larger,[4] graded primarily for

[3] Italic numbers in parentheses refer to Literature Cited, p. 26.
[4] In American lumber standards "posts and timbers" are 6 by 6 inches and larger.

use as posts or columns carrying longitudinal load but adapted to miscellaneous uses in which strength in bending is not especially important.

B. STRENGTH RATIO

The strength ratio[5] of a grade represents the remaining strength after making allowance for the maximum effect of the permitted knots, cross grain, shakes, and the like on a green piece. Thus, a strength ratio of 75 percent applies to a grade in which the maximum reduction in strength from that of green clear wood is 25 percent. Grades having strength ratios below 50 percent are not considered herein.

Beams and stringers, joist and plank, and posts and timbers may be described under a single grade name but the requirements need not be such as to afford the same strength ratio in each use class. Also, working stress in the extreme fiber of pieces used in bending is determined by the permitted knots and cross grain, whereas shearing stress depends on shakes and checks. Consequently, strength ratios for shear and for stress in extreme fiber may differ in the same grade and a ratio for each kind of stress is necessary to characterize a grade of beams and stringers or of joist and plank.

Economy may be served by specifying these ratios in such relation to each other that the allowable working stresses for shear and for extreme fiber will be in balance, under the loading for which the members are designed. Furthermore, timbers of high strength ratio should not be specified for use where stiffness is the controlling factor as is frequently true of joists above plastered ceilings because stiffness of timbers varies but little with the grade, and one value of modulus of elasticity is used for each species regardless of the strength ratio of the grade.

C. GRADE DESCRIPTIONS

Following are shown forms for the development of grade specifications for beams and stringers, for joists and plank, and for posts and timbers with blanks in which to insert the name of the grade, strength ratios, slope of grain, and sizes of knots, shakes, and wane as found from data given in the tables of part 2. Only features affecting strength are specified.[6] A complete specification should include also paragraphs covering requirements as to appearance, durability, susceptibility to preservative treatment, and other desired features,[7] as well as such definitions[8] as are essential to correct interpretation of the specification.

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[5] The allowable working stress for pieces used as a beam or as a column or of any grade for those purposes is found by multiplying the strength ratio by the basic stress. Because of the smaller effect of seasoning checks on material of smaller dimensions joist and plank are allowed higher working stresses when used where they will be continuously dry than are given by this method of computation. Basic stresses are given in part 4.

[6] Pieces whose use involves greater than ordinary hazards to human life such as scaffold plank should be specially graded for the intended use or an additional factor of safety should be applied in determining the size required.

[7] Examples of such paragraphs are included in the report of committee on wooden bridges and trestles, American Railway Engineering Association Bul. 314, February 1929, pp. 1186, 1187.

[8] Such definitions are given in Simplified Practice Recommendation R16-29 (*8*) and in Standard Definitions of Terms Relating to Timber. (*1*).

SPECIFICATION REQUIREMENTS[9] FOR BEAMS AND STRINGERS OF -- GRADE (BEAMS, GIRDERS, STRINGERS, ETC.)

100. The strength ratios of this grade are -- percent for stress in extreme fiber in bending and -- percent for stress in horizontal shear.

101. *Primary use.*—As beams with load applied on the narrow face.

102. *Nominal dimensions.*—Five inches and thicker and 8 inches and wider. Actual dimensions shall conform to the following: *Rough (unsurfaced) pieces shall be sawn full to nominal dimensions, except that occasional slight variation in sawing is permissible. At no part of the length shall any piece, because of such variation in sawing, be more than 3/16 inch under the nominal dimension when this is 7 inches or less nor more than 1/4 inch under the nominal dimension when this is 8 inches or greater. Further, no shipment shall contain more than 20 percent of pieces of minimum dimension.*

Surfacing, whether on one or both of a pair of opposite faces, shall leave the finished size not more than 1/2 inch under the nominal dimension.

103. *Quality of wood.*[10]—No piece of exceptionally light weight is permitted.

104. *Decay.*—Only pieces consisting of sound wood, free from any form of decay, incipient or advanced, including firm red heart, dote, and rot are acceptable.

105. *Slope of grain.*—Slope of grain is to be measured over a distance sufficiently great to define the general slope disregarding short local deviations. *Within the middle half of the length of the piece*[11] the slope shall not be steeper than ---.[12]

106. The size of knot on a narrow face is taken as the width between lines enclosing the knot and parallel to the edges of the piece except that when a knot on a narrow face extends into the adjacent one-fourth of the width of a wide face its least dimension is taken as its size.

107. The size of a knot on a wide face is its smallest diameter.

108. Shakes are measured at the ends of the piece. *Only those within the middle half of the height of the piece are considered. (Height equals width of wide face.)* The size of a shake is the distance between lines enclosing the shake and parallel to the wide faces of the piece. *The permissible size is determined by the width of the narrow face of the piece.*

109. Maximum permissible sizes of knots and shakes[13] are shown in the following schedule:

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[9] These requirements are for pieces to be used over single spans. The limitations applied to the middle third of the length (pars. 109 and 111) and to the middle half of the length (par. 105) should be applied to the middle two thirds of the length of pieces to be used over double spans and to the entire length of pieces to be used over three or more spans. They should also be applied to the entire length of pieces to be subjected to longitudinal tension. The strength ratio for tension will then be equal to the ratio for stress in extreme fiber in bending. Such members as caps and bridge ties are often square or have horizontal faces wider than vertical faces in contrast to beams and stringers in which narrow and wide faces are horizontal and vertical, respectively. In applying the requirements of beam and stringer grades to such material it should be kept in mind that as used herein narrow face means horizontal face or the face to which the load is applied, and wide face means the vertical, or other, face.

[10] In certain species material selected for "close grain" or for "density" may be specified. Definitions of dense and close grain as applied to Douglas fir and southern pines are included in Simplified Practice Recommendation R16-29 (8) and in publications of the American Society for Testing Materials and the American Railway Engineering Association.

[11] If a piece complies with this requirement and the limitations of sizes of knots no limitation of slope of grain in other parts of the piece is needed.

[12] Insert value from column 1 of table 1, according to the strength ratio for stress in extreme fiber as specified in par. 100.

[13] The following is an alternative to the schedule of sizes of shakes given in par. 109 and is designated par. 109a: The size of shake shall not exceed --of the width of the end of a green piece nor --of the width of end of a seasoned piece. (Values for the blanks in par. 109a are found from equations given at the end of table 5, sections A and B.

Size of knot		Nominal width of face or end	Size of shake	
On narrow face within middle third of length	Along center line of wide face		In green piece	In seasoned piece
1	2	3	4	5
Inches (Find sizes from table 2, according to width of face and the strength ratio for stress in extreme fiber, as specified in par. 100.)	*Inches* (Find sizes from table 3, according to width of face and the strength ratio for stress in extreme fiber as specified in par. 100.)	*Inches* 5 6 8 10 Etc.	*Inches* (Find sizes from section A of table 5, according to width of end and the strength ratio for stress in horizontal shear as specified in par. 100.)	*Inches* (Find sizes from section B of table 5, according to width of end and the strength ratio for stress in horizontal shear as specified in par. 100.)

110. Knots at edges of wide faces are limited to the same sizes as on the narrow faces *of the same piece* but are measured according to paragraph 107.

111. The sizes of knots on narrow faces and at edges of wide faces may increase proportionately from the size permitted in the middle third of the length to twice that size at the ends of the piece *except that the size of no knot shall exceed the size permitted along the center line of the wide face.*

112. The size of knots on wide faces may increase proportionately from the size permitted at the edge to the size permitted along the center line.

113. Cluster knots and knots in groups are not permitted.

114. The sum of the sizes of all knots within the middle half of the length of any face *measured as specified by paragraphs 106 or 107 for the face under consideration* shall not *exceed four times the size of the largest knot allowed on that face.*[14]

115. Knot holes and holes from causes other than knots are measured and limited as provided for knots.

116.[15] *Checks and splits are measured and limited in the same way as shakes. The following limitations apply to both ends but only within the middle half of the height of the piece and within three times the height from the end. (Height equals width of wide face.) The size of checks within this portion of the piece shall be taken as their estimated area, along the horizontal section showing maximum area, divided by three times the height of the piece. When checks on two parallel faces are opposite or approximately so, the sum of their sizes is taken. The sum of the sizes of shakes, checks, and/or splits shall not exceed the permissible size of shake.*

Checks extending entirely across the end within the middle half of the height shall not extend into the piece at the center of the width of the end a distance greater than the size of the allowable shake.

117. Wane at any point on any face shall not exceed __ [16] the width of the face.

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[14] Better adapted to specifications for grades of a variety of strength ratios than the American lumber standards limitation of sum of knots as a fraction or multiple of the width of face—equivalent to American lumber standards for narrow faces up to 6 inches and for wide faces up to 12 inches, but more restrictive for wider faces.

[15] Revised to include splits and avoid rejections because of checks localized at the ends and to measure checks more nearly in accordance with their actual effect. The revision is based on work of a special subcommittee of the American Society for Testing Materials.

[16] Insert fraction from table 7, according to the strength ratio for stress in extreme fiber as specified in par. 100.

SPECIFICATION REQUIREMENTS[17] FOR JOIST AND PLANK OF -- GRADE (JOISTS, RAFTERS, PLANKS, FACTORY AND BRIDGE FLOORING, ETC.)

200. The strength ratios of this grade are -- percent for stress in extreme fiber and -- percent for stress in horizontal shear.

201. *Primary use.*—As beams with load applied to either the wide or the narrow face.

202. *Nominal dimensions.*—Two to four inches in thickness and 4 inches and wider. Actual dimensions shall conform to the following: *Rough (unsurfaced) pieces shall be sawn full to nominal dimension except that occasional slight variation in sawing is permissible. At no part of the length shall any piece because of such variation be more than 3/16 inch under the nominal dimension when this is 3 to 7 inches inclusive, nor more than 1/4 inch under the nominal dimension when this is 8 inches or greater. The actual thickness of nominal 2-inch material shall not be less than 1 7/8 inches at any part of the length. Further, no shipment shall contain more than 20 percent of pieces of minimum dimension.*

Surfacing, whether on one or both of a pair of opposite faces, shall leave the finished size not more than 3/8 inch under the nominal dimension when this is 7 inches or less and not more than 1/2 inch under the nominal dimension when this is 8 inches or more.

203. *Quality of wood.*[18]—No piece of exceptionally light weight is permitted.

204. *Decay.*—Only pieces consisting of sound wood, free from any form of decay, incipient or advanced, including firm red heart, dote, and rot are acceptable.

205. *Slope of grain.*—Slope of grain is to be measured over a distance sufficiently great to determine the general slope disregarding slight local deviations. *Within the middle half of the length of the piece*[19] the slope shall not be steeper than --.[20]

206. The size of a knot on a narrow face is taken as the width between lines enclosing the knot and parallel to the edges of the piece. *The only knots measured on the narrow faces of the piece are those that do not show on the wide faces.*[21]

207. The size of a knot on a wide face is the average diameter of the knot as found by halving the sum of its largest and smallest diameters. *The size of a spike knot is the half sum of its length and its greatest width.*

208. Shakes are measured at the ends of the piece. *Only those within the middle half of the height of the piece are considered. (Height equals width of wide face.)* The size of a shake is the distance between lines enclosing the shake and parallel to the wide *faces of the piece. The permissible size is determined by the width of the narrow face of the piece.*

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[17] The limitations applied to the middle third of the length of the piece (pars. 209 and 210) and to the middle half of the length (par. 205) should be applied to the entire length of pieces to be subjected to longitudinal tension. The strength ratio for tension will then be equal to the ratio for stress in the extreme fiber in bending. These limitations should also be applied to the entire length of pieces such as flooring, to be used over three or more spans.

[18] In certain species material selected for "close grain" or for "density" may be specified. Definitions of dense and close grain as applied to Douglas fir and southern pines are included in Simplified Practice Recommendation R16-29 (*8*) and in publications of the American Society for Testing Materials and the American Railway Engineering Association.

[19] If a piece complies with this requirement and the limitations of sizes of knots no limitation of slope or grain in other parts of the piece is needed.

[20] Insert value from column 1 of table 1 according to the strength ratio for stress in extreme fiber, as specified in paragraph 200.

[21] Addition to American lumber standards to cover those side-cut pieces having knots that show only on narrow faces as well as box-heart pieces.

209. Maximum permissible sizes of knots and shakes [22] are shown in the following schedule:

Size of knot			Nominal width of face or end	Size of shake	
Within middle third of length		Along center line of wide face		In green piece	In seasoned piece
On narrow face	At edge of wide face				
1	2	3	4	5	6
Inches (Find sizes from table 2 according to width of face and the strength ratio for stress in extreme fiber as specified in par. 200.)	*Inches* (Find sizes from table 4 according to width of face and the strength ratio for stress in extreme fiber as specified in par. 200.)	*Inches* (Find sizes from table 3 according to width of face and the strength ratio for tress in extreme fiber as specified in par. 200.)	*Ins.* 2 3 4 6 8 Etc.	*Inches* (Find sizes from section A of table 5 according to width of end and the strength ratio for stress in horizontal shear as specified in par. 200.)	*Inches* (Find sizes from section B of table 5 according to width of end and the strength ratio for stress in horizontal shear as specified in par. 200.)

210. The sizes of knots on narrow faces and at edges of wide faces may increase proportionately from the size permitted in the middle third of the length to twice that size at the ends of the piece.

211. The size of knots on wide faces may increase proportionately from the size permitted at the edge to the size permitted along the center line.

212. Cluster knots and knots in groups are not permitted.

213. The sum of the sizes of all knots within the middle half of the length of any face, *measured as specified by paragraph 206 or 207 for the face under consideration,* shall not exceed *four and one half times the size of the largest knot allowed on that face.*[23]

214. Knot holes and holes from causes other than knots are measured and limited as provided for knots.

[24] 215. *Checks and splits are measured and limited in the same way as shakes.—The following limitations apply to both ends but only within the middle half of the height of the piece and within three times the height from the end. (Height equals width of wide face.) The size of checks within this portion of the piece shall be taken as their estimated area, along the horizontal section showing maximum area, divided by three times the height of the piece. When checks on two parallel faces are opposite or approximately so, the sum of their sizes is taken. The sum of the sizes of shakes, checks, and/or splits shall not exceed the permissible size of shake.*

Checks extending entirely across the end within the middle half of the height shall not extend into the piece at the center of the width of the end a distance greater than the size of the allowable shake.

216. Wane at any point on any face shall not exceed --[25] the width of the face.

[22] The following is an alternative to the schedule of sizes of shakes given in par. 209 and is designated par. 209a: The size of shake shall not exceed -- of the width of the end of a green piece nor -- of the width of end of a seasoned piece. (Values for the blanks in par. 209a are found from equations given at the end of table 5, sections A and B.)

[23] Better adapted to specifications for grades of a variety of strength ratios than the American lumber standards limitation of sum of knots as a fraction or multiple of the width of face—equivalent to American lumber standards for narrow faces and for wide faces up to 12 inches, but more restrictive for wider faces.

[24] Revised to include splits and avoid rejections because of checks localized at the ends and to measure checks more nearly in accordance with their actual effect. The revision is based on work of a special subcommittee of the American Society for Testing Materials.

[25] Insert fraction from table 7 according to the strength ratio for stress in extreme fiber as specified in par. 200.

SPECIFICATION REQUIREMENTS FOR POSTS AND TIMBERS OF -- GRADE (POSTS, COLUMNS, STRUTS, CAPS, SILLS, ETC.)

300. The strength ratio of this grade is -- percent for stress in compression parallel to grain.

301. *Primary use.*—As posts or columns to carry longitudinal loads in compression.

302. *Nominal dimensions.*—Four by four inches and larger. Actual dimensions shall conform to the following: *Rough (unsurfaced) pieces shall be sawn full to nominal dimensions except that occasional slight variation in sawing is permissible. At no part of the length shall any piece, because of such variation, be more than 3/16 inch under the nominal dimension when this is 3 to 7 inches or less, nor more than 1/4 inch under the nominal dimension when this is 8 inches or greater. Further, no shipment shall contain more than 20 percent of pieces of minimum dimensions.*

Surfacing, whether on one or both of a pair of opposite faces, shall leave the finished size not more than 3/8 inch under the nominal dimension when this is 4 or 5 inches and not more than 1/2 inch under the nominal dimension when this is 6 inches or greater.

303. *Quality of wood.*[26]—No piece of exceptionally light weight is permitted.

304. *Decay.*—Only pieces consisting of sound wood, free from any form of decay, incipient or advanced, including firm red heart, dote, and rot are acceptable.

305. *Slope of grain.*—Slope of grain is to be measured over a distance sufficiently great to determine the general slope disregarding slight local deviations. The slope shall not be steeper than -- [27] *in any part of the piece.*

306. The size of a knot is half the sum of its largest and smallest diameters. *The size of a spike knot is half the sum of its length and its greatest width.*

307. Shakes are measured at the ends of the piece. The size of a shake is the distance between lines enclosing the shake and parallel to a pair of opposite faces.

308. Maximum permissible sizes of knots and shakes [28] are shown in the following schedule:

Size of knot	Nominal width of piece	Size of shake	
		In green piece	In seasoned piece
1	2	3	4
Inches	*Inches*	*Inches*	*Inches*
(Find size from table 3 according to width of piece and the strength ratio as specified in par. 300.)	4 5 6 8 10 Etc.	(Find size from section A of table 6 according to width of piece and the strength ratio as specified in par. 300.)	(Find size from section B of table 6 according to width of piece and the strength ratio as specified in par. 300.)

The maximum size of knot in this schedule applies at any point in the width and/or length of the face.

309. Cluster knots and knots in groups are not permitted.

[26] In certain species material selected for "close grain" or for "density" may be specified. Definitions of dense and close grain as applied to Douglas fir and southern pines are included in Simplified Practice Recommendation R16-29 (*8*) and in publications of the American Society for Testing Materials and the American Railway Engineering Association.

[27] Insert value from column 1 of table 1, according to the strength ratio, as specified in par. 300.

[28] The following is an alternative to the schedule of sizes of shakes given in par. 308: 308a. The size of shake shall not exceed -- of the width of the end of a green piece nor -- of the width of end of a seasoned piece. (Values for the blanks in par. 308 are found from equations given at the end of table 6.)

310. The sum of the sizes of all knots in any 6 inches of the length of the piece, *measured as specified by paragraph 306*, is not permitted to exceed twice the maximum permissible size of knot. Two knots of maximum permissible size are not allowed in the same 6 inches of length on any face.

311. Knot holes and holes from causes other than knots are measured and limited as provided for knots.

312.[29] *Checks and splits are measured and limited in the same way as shakes.—The size of checks within three times the width of the piece from either end shall be taken as their estimated area, along the longitudinal section showing maximum area, divided by three times the width of the piece. The sum of the sizes of shakes, checks, and/or splits shall not exceed the permissible size of shake.*

Checks extending entirely across the end shall not extend into the piece at the center of the width of the end, a distance greater than the size of the allowable shake.

313. *Wane at any point on any face shall not exceed* -- [30] *the width of the face.*

PART 2. TABLES OF PERMISSIBLE SLOPES OF GRAIN AND SIZES OF KNOTS, SHAKES, AND WANE WITH EXAMPLES OF THEIR USE

Tables 1 to 7 supply values to be inserted in the blanks in part 1 to make specifications for grades having strength ratios as desired. They may also be used to find from the limitations set up in the description of any grade or from inspection of an individual piece the strength ratio or ratios that apply, and when the strength ratio is known the appropriate working stress can be found by the method outlined in part 4.

These tables include data for the description of grades having strengths within the range of 50 to 100 percent of that of clear green material.[31] Timbers having very high strength ratios can ordinarily be produced only in limited quantities and from parts of the tree that are especially valuable for other products. Greater perfection than is practically attainable or is economical for the intended use should not be specified.

A. SLOPE OF GRAIN

Table 1 gives strength ratios for stress in extreme fiber in bending for various values of slopes of grain.

TABLE 1.—*Strength ratios corresponding to various slopes of grain*

Slope of grain	Maximum strength ratio: For stress in extreme fiber in bending (beams and stringers (par. 105) or joist and plank (par. 205))	Maximum strength ratio: For stress in compression parallel to grain (posts and timbers (par. 305))	Slope of grain	Maximum strength ratio: For stress in extreme fiber in bending (beams and stringers (par. 105) or joist and plank (par. 205))	Maximum strength ratio: For stress in compression parallel to grain (posts and timbers (par. 305))
1	2	3	1	2	3
	Percent	Percent		Percent	Percent
1 in 6	----------	56	1 in 15	76	100
1 in 8	53	66	1 in 16	80	----------
1 in 10	61	74	1 in 18	85	----------
1 in 12	69	82	1 in 20	100	----------
1 in 14	74	87			

[29] See footnote to par. 116.
[30] Insert fraction from table 7 according to the strength ratio, as specified in par. 300.
[31] See DETERMINATION OF WORKING STRESSES, p. 21.

B. KNOTS

Strength ratios for various combinations of size of knot and width of face are given in tables 2, 3, and 4.

If, for example,[32] the sizes of knots permissible in an 8- by 16-inch (nominal dimensions) piece in a grade having a strength ratio of 70 percent for stress in extreme fiber in bending are desired, proceed as follows: The smallest ratio in the column for 8-inch face in table 2 (narrow face) that equals or exceeds 70 percent is opposite 2⅛ inches in the "size of knot" column and a similar ratio in the column for 16-inch face in table 3 (wide face) is opposite 4¼ inches. Hence, the permissible sizes are 2⅛ inches on the 8-inch face and 4¼ inches along the center line of the 16-inch face.

TABLE 2.—*Strength ratios corresponding to various combinations of size of knot and width of face*

Beams and Stringers / **Joist and Plank** — **Knots on Narrow Face. Within Middle Third of Length of Piece. Strength Ratios for Stress in Extreme Fiber in Bending.**

[Sizes of knots for col. 1, par. 109, or col. 1, par. 209]

Size of knot (inches)	Percentage strength ratios for nominal face width (inches) indicated										Size of knot (inches)	Percentage strength ratios for nominal face width (inches) indicated									
	2	3	4	5	6	8	10	12	14	16		2	3	4	5	6	8	10	12	14	16
¼	90	93	95	96	96	97	97	97	98	98	2⅝	----	----	----	----	57	63	67	70	72	74
⅜	83	89	92	93	94	95	96	96	96	97	2¾	----	----	----	----	55	61	65	68	70	72
½	77	85	88	91	92	93	94	95	95	95	2⅞	----	----	----	----	53	59	63	67	69	71
⅝	71	81	85	88	90	92	92	93	94	94	3	----	----	----	----	51	57	62	65	68	70
¾	65	76	82	86	88	90	91	92	92	93	3⅛	----	----	----	----	----	55	60	64	66	68
⅞	58	72	79	83	86	88	89	90	91	91	3¼	----	----	----	----	----	54	59	62	65	67
1	52	68	76	81	84	86	88	89	89	90	3⅜	----	----	----	----	----	52	57	61	64	66
1⅛	----	64	73	78	82	84	86	87	88	89	3½	----	----	----	----	----	50	55	59	62	65
1¼	----	60	70	76	80	83	84	86	87	88	3⅝	----	----	----	----	----	----	54	58	61	63
1⅜	----	56	67	73	78	81	83	84	85	86	3¾	----	----	----	----	----	----	52	56	59	62
1½	----	51	63	71	76	79	81	83	84	85	3⅞	----	----	----	----	----	----	50	55	58	61
1⅝	----	----	60	68	74	77	80	81	83	84	4	----	----	----	----	----	----	----	53	57	60
1¾	----	----	57	66	71	75	78	80	81	83	4⅛	----	----	----	----	----	----	----	52	55	58
1⅞	----	----	54	63	69	73	76	78	80	81	4¼	----	----	----	----	----	----	----	50	54	57
2	----	----	51	61	67	72	75	77	79	80	4⅜	----	----	----	----	----	----	----	----	53	56
2⅛	----	----	----	58	65	70	73	75	77	79	4½	----	----	----	----	----	----	----	----	51	54
2¼	----	----	----	56	63	68	71	74	76	77	4⅝	----	----	----	----	----	----	----	----	50	53
2⅜	----	----	----	53	61	66	70	72	74	76	4¾	----	----	----	----	----	----	----	----	----	52
2½	----	----	----	51	59	64	68	71	73	75	4⅞	----	----	----	----	----	----	----	----	----	51

[32] The sizes of knots or shakes corresponding to various strength ratios when computed by definite rules involve decimals. A reasonable rule for changing these decimals to common fractions is to hold to one fraction until the computed size is two thirds the way to the next fraction. Thus, when fractions differ by eighths of an inch, only decimals greater than 2, 5, 8, 11, 14, 17, 20, or 23 twenty fourths are "rounded" to the next higher size. The equivalent of this conversion method is to subtract from each size of knot or shake one third the difference between successive sizes before computing the corresponding strength ratio. Tables 2 to 6, inclusive, have been computed on this basis, the difference between successive sizes being taken as one eighth inch. For example, the strength ratios listed for a 3½-inch knot are those that actually would obtain for a size of 3¹¹⁄₂₄ inches. In view of the allowance thus introduced and the fact that nominal instead of actual widths of face have been used, the strength ratios in tables 2 to 6, inclusive, should be taken as maximums.

TABLE 3.—*Strength ratios corresponding to various combinations of size of knot and width of face*

Beams and Stringers .... **Joist and Plank**	**Knots Along Center Line of Wide Face at any Point in the Length of the Piece. Strength Ratios for Stress in Extreme Fiber in Bending.**
Posts and Timbers	**Knots at any Point on any Face. Strength Ratios for Stress in Compression Parallel to Grain.**

[Sizes of knots for col. 2, par. 109; col. 3, par. 209; or col. 1, par. 308]

Size of knot [1] (inches)	Percentage strength ratios for nominal face width (inches) indicated												Size of knot [1] (inches)	Percentage strength ratios for nominal face width (inches) indicated											
	4	5	6	8	10	12	14	16	18	20	22	24		4	5	6	8	10	12	14	16	18	20	22	24
¼	95	96	96	97	98	98	98	98	99	99	99	99	4½	---	---	---	---	55	63	66	68	70	71	73	74
½	88	91	92	94	95	96	96	97	97	97	97	97	4¾	---	---	---	---	53	61	64	66	68	70	71	72
¾	82	86	88	91	93	94	94	95	95	95	96	96	5	---	---	---	---	50	59	62	64	66	68	70	71
1	76	81	84	88	90	92	93	93	93	94	94	94	5¼	---	---	---	---	---	57	60	62	65	66	68	69
1¼	70	76	80	85	88	90	91	91	92	92	93	93	5½	---	---	---	---	---	54	58	61	63	65	66	68
1½	63	71	76	82	85	88	89	89	90	91	91	91	5¾	---	---	---	---	---	52	56	59	61	63	65	66
1¾	57	66	71	79	83	86	87	88	88	89	89	90	6	---	---	---	---	---	50	54	57	59	61	63	65
2	51	61	67	75	80	84	85	86	87	87	88	88	6¼	---	---	---	---	---	---	52	55	58	60	62	63
2¼	---	56	63	72	78	82	83	84	85	86	86	87	6½	---	---	---	---	---	---	50	53	56	58	60	62
2½	---	51	59	69	75	79	81	82	83	84	85	85	6¾	---	---	---	---	---	---	---	52	54	57	59	60
2¾	---	---	55	66	73	77	79	80	82	82	83	84	7	---	---	---	---	---	---	---	50	53	55	57	59
3	---	---	51	63	70	75	77	79	80	81	82	83	7¼	---	---	---	---	---	---	---	---	51	53	56	57
3¼	---	---	---	60	68	73	75	77	78	79	80	81	7½	---	---	---	---	---	---	---	---	---	52	54	56
3½	---	---	---	57	65	71	73	75	76	78	79	80	7¾	---	---	---	---	---	---	---	---	---	50	53	55
3¾	---	---	---	54	63	69	71	73	75	76	77	78	8	---	---	---	---	---	---	---	---	---	---	51	53
4	---	---	---	50	60	67	69	71	73	74	76	77	8¼	---	---	---	---	---	---	---	---	---	---	---	52
4¼	---	---	---	---	58	65	67	70	71	73	74	75	8½	---	---	---	---	---	---	---	---	---	---	---	50

[1] Ratios corresponding to other sizes of knot can be found by interpolation.

TABLE 4.—*Strength ratios corresponding to various combinations of size of knot and width of face*

Joist and Plank	**Knots at Edge of Wide Face Within Middle Third of Length of Piece. Strength Ratios for Stress in Extreme Fiber in Bending.**

[Sizes of knots for col. 2, par. 209]

Size of knot (inches)	Percentage strength ratios for nominal face width (inches) indicated											Size of knot (inches)	Percentage strength ratios for nominal face width (inches) indicated										
	4	6	8	10	12	14	16	18	20	22	24		4	6	8	10	12	14	16	18	20	22	24
¼	90	93	95	96	97	97	97	97	97	97	98	2¾	---	---	---	53	60	63	65	66	68	69	71
⅜	84	89	92	93	94	95	95	95	96	96	96	2⅞	---	---	---	51	58	61	63	65	67	68	69
½	78	85	89	91	92	93	93	94	94	94	95	3	---	---	---	50	57	60	62	64	65	67	68
⅝	73	81	86	89	90	91	92	92	93	93	93	3⅛	---	---	---	---	55	58	60	62	64	66	67
¾	68	78	83	86	88	89	90	91	91	91	92	3¼	---	---	---	---	54	57	59	61	63	64	66
⅞	63	74	80	84	87	88	88	89	89	90	90	3⅜	---	---	---	---	52	55	58	60	62	63	65
1	58	71	77	82	85	86	87	87	88	89	89	3½	---	---	---	---	51	54	56	58	60	62	63
1⅛	53	67	75	79	83	84	85	86	86	87	88	3⅝	---	---	---	---	---	52	55	57	59	61	62
1¼	---	64	72	77	81	82	83	84	85	86	86	3¾	---	---	---	---	---	51	54	56	58	60	61
1⅜	---	60	69	75	79	80	82	83	83	84	85	3⅞	---	---	---	---	---	50	52	55	57	58	60
1½	---	57	67	73	77	79	80	81	82	83	84	4	---	---	---	---	---	---	51	53	55	57	59
1⅝	---	54	64	71	75	77	78	80	81	81	82	4⅛	---	---	---	---	---	---	50	52	54	56	58
1¾	---	51	62	69	74	75	77	78	79	80	81	4¼	---	---	---	---	---	---	---	51	53	55	57
1⅞	---	---	59	67	72	74	75	77	78	79	80	4⅜	---	---	---	---	---	---	---	50	52	54	55
2	---	---	57	65	70	72	74	75	76	77	78	4½	---	---	---	---	---	---	---	---	51	53	54
2⅛	---	---	55	63	68	70	72	74	75	76	77	4⅝	---	---	---	---	---	---	---	---	50	51	53
2¼	---	---	52	61	67	69	71	72	73	75	76	4¾	---	---	---	---	---	---	---	---	---	50	52
2⅜	---	---	50	59	65	67	69	71	72	73	74	4⅞	---	---	---	---	---	---	---	---	---	---	51
2½	---	---	---	57	63	66	68	69	71	72	73	5	---	---	---	---	---	---	---	---	---	---	50
2⅝	---	---	---	55	62	64	66	68	69	71	72												

C. SHAKES

Tables 5 and 6 show the strength ratios corresponding to various combinations of size of shakes and width of end.

TABLE 5.—*Strength ratios corresponding to various combinations of size of shake and width of end of piece*

Beams and Stringers.................. } Strength Ratios for Stress in Horizontal
Joist and Plank...................... } Shear

SECTION A—GREEN MATERIAL

[Sizes of shake for col. 4, par. 109,[1] or col. 5, par. 209 [1]]

Size of shake (inches)	Percentage strength ratios for nominal end width of piece (inches) indicated									
	2	3	4	5	6	8	10	12	14	16
1/4	90	93	95	96	96	97	98	98	98	99
3/8	83	89	92	93	94	96	97	97	98	98
1/2	77	85	88	91	92	94	95	96	97	97
5/8	71	81	85	88	90	93	94	95	96	96
3/4	65	76	82	86	88	91	93	94	95	96
7/8	58	72	79	83	86	90	92	93	94	95
1	52	68	76	81	84	88	90	92	93	94
1 1/8	----	64	73	78	82	86	89	91	92	93
1 1/4	----	60	70	76	80	85	88	90	91	92
1 3/8	----	56	67	73	78	83	87	89	90	92
1 1/2	----	51	63	71	76	82	85	88	90	91
1 5/8	----	----	60	68	74	80	84	87	89	90
1 3/4	----	----	57	66	71	79	83	86	88	89
1 7/8	----	----	54	63	69	77	82	85	87	88
2	----	----	51	61	67	75	80	84	86	88
2 1/8	----	----	----	58	65	74	79	83	85	87
2 1/4	----	----	----	56	63	72	78	82	84	86
2 3/8	----	----	----	53	61	71	77	81	83	85
2 1/2	----	----	----	51	59	69	75	79	82	85
2 5/8	----	----	----	----	57	68	74	78	81	84
2 3/4	----	----	----	----	55	66	73	77	81	83
2 7/8	----	----	----	----	53	65	72	76	80	82

Size of shake (inches)	Percentage strength ratios for nominal end width of piece (inches) indicated									
	2	3	4	5	6	8	10	12	14	16
3 [2]	----	----	----	----	51	63	70	75	79	81
3 1/4	----	----	----	----	----	60	68	73	77	80
3 1/2	----	----	----	----	----	57	65	71	75	78
3 3/4	----	----	----	----	----	54	63	69	73	77
4	----	----	----	----	----	50	60	67	72	75
4 1/4	----	----	----	----	----	----	58	65	70	74
4 1/2	----	----	----	----	----	----	55	63	68	72
4 3/4	----	----	----	----	----	----	53	61	66	71
5	----	----	----	----	----	----	50	59	65	69
5 1/4	----	----	----	----	----	----	----	57	63	67
5 1/2	----	----	----	----	----	----	----	54	61	66
5 3/4	----	----	----	----	----	----	----	52	59	64
6	----	----	----	----	----	----	----	50	57	63
6 1/4	----	----	----	----	----	----	----	----	56	61
6 1/2	----	----	----	----	----	----	----	----	54	60
6 3/4	----	----	----	----	----	----	----	----	52	58
7	----	----	----	----	----	----	----	----	50	56
7 1/4	----	----	----	----	----	----	----	----	----	55
7 1/2	----	----	----	----	----	----	----	----	----	53
7 3/4	----	----	----	----	----	----	----	----	----	52
8	----	----	----	----	----	----	----	----	----	50

[1] Values for par. 109a or 209a may be found from the following equation: $S=\frac{100-R}{100}$, where R is the strength ratio in percent and S is the permissible size of shake stated as a fraction of the nominal width of the end of the piece.

[2] Ratios for sizes of shake other than those listed between 3 and 8 inches can be found by interpolation.

TABLE 5.—*Strength ratios corresponding to various combinations of size of shake and width of end of piece*—Continued

Beams and Stringers________________ } Strength Ratios for Stress in Horizontal
Joist and Plank____________________ } Shear

SECTION B—SEASONED MATERIAL

[Sizes of shake for col. 5, par. 109,[3] or col. 6, par. 209 [3]]

Size of shake (inches)	Percentage strength ratios for nominal end width of piece (inches) indicated									
	2	3	4	5	6	8	10	12	14	16
¼	100	100	100	100	100	100	100	100	100	100
⅜	94	100	100	100	100	100	100	100	100	100
½	87	95	100	100	100	100	100	100	100	100
⅝	80	91	96	99	100	100	100	100	100	100
¾	73	86	93	97	99	100	100	100	100	100
⅞	66	81	89	94	97	100	100	100	100	100
1	59	77	85	91	94	99	100	100	100	100
1⅛	52	72	82	88	92	97	100	100	100	100
1¼	----	67	78	85	90	95	99	100	100	100
1⅜	----	62	75	82	87	94	97	100	100	100
1½	----	58	71	80	85	92	96	99	100	100
1⅝	----	53	68	77	83	90	95	98	100	100
1¾	----	----	64	74	80	88	93	96	99	100
1⅞	----	----	61	71	78	87	92	95	98	100
2	----	----	57	68	76	85	90	94	97	99
2⅛	----	----	54	66	73	83	89	93	96	98
2¼	----	----	50	63	71	81	88	92	95	97
2⅝	----	----	----	60	69	80	86	91	94	96
2½	----	----	----	57	66	78	85	89	93	95
2⅝	----	----	----	54	64	76	83	88	92	94
2¾	----	----	----	52	62	74	82	87	91	93
2⅞	----	----	----	----	59	73	81	86	90	93
3 [4]	----	----	----	----	57	71	79	85	89	92
3¼	----	----	----	----	52	67	76	82	87	90

Size of shake (inches)	Percentage strength ratios for nominal end width of piece (inches) indicated									
	2	3	4	5	6	8	10	12	14	16
3½	----	----	----	----	48	64	74	80	85	88
3¾	----	----	----	----	----	60	71	78	83	86
4	----	----	----	----	----	57	68	75	81	85
4¼	----	----	----	----	----	53	65	73	79	83
4½	----	----	----	----	----	50	62	71	77	81
4¾	----	----	----	----	----	----	59	68	75	79
5	----	----	----	----	----	----	57	66	73	78
5¼	----	----	----	----	----	----	54	64	71	76
5½	----	----	----	----	----	----	51	61	69	74
5¾	----	----	----	----	----	----	----	59	67	72
6	----	----	----	----	----	----	----	57	65	71
6¼	----	----	----	----	----	----	----	54	63	69
6½	----	----	----	----	----	----	----	52	61	67
6¾	----	----	----	----	----	----	----	50	59	65
7	----	----	----	----	----	----	----	----	57	64
7¼	----	----	----	----	----	----	----	----	55	62
7½	----	----	----	----	----	----	----	----	53	60
7¾	----	----	----	----	----	----	----	----	51	58
8	----	----	----	----	----	----	----	----	----	56
8¼	----	----	----	----	----	----	----	----	----	55
8½	----	----	----	----	----	----	----	----	----	53
8¾	----	----	----	----	----	----	----	----	----	51
9	----	----	----	----	----	----	----	----	----	49

[3] Values for par. 109a or 209a may be found from the following equation: $S=\frac{900-8R}{900}$, where R is the strength ratio in percent and S is the permissible size of shake stated as a fraction of the nominal width of the end of the piece.

[4] Ratios for sizes of shake other than those listed between 3 and 9 inches can be found by interpolation.

Only widths of end up to 12 inches are listed in table 6. Sizes of shakes for wider ends can be found by addition. For example, the sizes in green material for a strength ratio of 60 percent are interpolated from section A for widths of 6 and 8 inches as 3⅛ and 4⅛ inches, respectively. Then the allowable size for a width of 14 inches is 7¼ inches.

TABLE 6.—*Strength ratios corresponding to various combinations of size of shake and width of end of piece* [1]

Posts and Timbers________________ { **Strength Ratios for Stress in Compression Parallel to Grain**

Size of shake,[3] inches	Section A—green material (sizes of shake, for col. 3, par. 308 [2]) Percentage strength ratios for nominal end width of piece (inches) indicated						Section B—seasoned material (sizes of shake for col. 4, par. 308 [2]) Percentage strength ratios for nominal end width of piece (inches) indicated					
	4	5	6	8	10	12	4	5	6	8	10	12
3/4	100	100	100	100	100	100	100	100	100	100	100	100
1	95	100	100	100	100	100	100	100	100	100	100	100
1 1/4	87	95	100	100	100	100	100	100	100	100	100	100
1 1/2	79	89	95	100	100	100	92	100	100	100	100	100
1 3/4	72	82	89	98	100	100	84	95	100	100	100	100
2	64	76	84	94	100	100	76	88	97	100	100	100
2 1/4	56	70	79	90	97	100	68	82	91	100	100	100
2 1/2	48	63	74	87	94	99	61	76	86	99	100	100
2 3/4		57	69	83	91	97	53	70	81	95	100	100
3		51	63	79	88	94	45	63	76	91	100	100
3 1/4			58	75	85	92		57	71	87	97	100
3 1/2			53	71	82	89		51	65	83	94	100
3 3/4			48	67	79	86			60	80	91	99
4				63	75	84			55	76	88	96
4 1/4				59	72	81			50	72	85	94
4 1/2				55	69	79				68	82	91
4 3/4				51	66	76				64	79	88
5					63	73				60	75	86
5 1/4					60	71				56	72	83
5 1/2					57	68				52	69	81
5 3/4					54	65				48	66	78
6					50	63					63	75
6 1/4						60					60	73
6 1/2						58					57	70
6 3/4						55					54	68
7						52					50	65
7 1/4						50						62
7 1/2												60
7 3/4												57
8												55
8 1/4												52
8 1/2												49

[1] See discussion of shake in par. 6, pt. 3.

[2] Values for paragraph 308a may be found from the following equations: For green material $S=\frac{1{,}000-8R}{1{,}000}$. For seasoned material $S=\frac{1{,}100-8R}{1{,}000}$, where R is the strength ratio in percent and S is the permissible size of shake stated as a fraction of the nominal width of the face.

[3] Ratios for sizes intermediate to those listed can be found by interpolation.

D. WANE

Table 7 gives strength ratios for various widths of wane. It applies to beams and stringers, joist and plank, or posts and timbers.

TABLE 7.—*Strength ratios corresponding to various widths of wane* [1]

Beams and Stringers________________ { **Strength Ratios for Stress in Extreme**
Joist and Plank____________________ { **Fiber in Bending**

Posts and Timbers________________ { **Strength Ratios for Stress in Compression Parallel to Grain**

[Values of wane for pars. 117, 216, and 313]

Width of wane—fraction of nominal width of face (inches)	Strength ratio
1/4	50 percent up to and including 60 percent.
1/5	Above 60 percent up to and including 66 percent.
1/6	Above 66 percent up to and including 75 percent.
1/8	Above 75 percent up to and including 87 percent.
1/10	Above 87 percent.

[1] See discussion of wane, par. 7, pt. 3.

EXAMPLES FOR THE USE OF TABLES 1 TO 7 IN CONSTRUCTING SPECIFICATIONS

The following examples illustrate the use of the data given in part 2 for filling the blanks in the specification forms of part 1.

The procedure is to decide first on what strength ratio or ratios the grade is to conform to and then to use tables 1 to 7 to find the permissible slope of grain and sizes of knots, shakes, and wane.

In these examples only those specification paragraphs that are varied according to the strength ratio of the grade are reproduced.

EXAMPLE 1.—SPECIFICATION REQUIREMENTS FOR BEAMS AND STRINGERS OF X GRADE

100. The strength ratios of this grade are 70 percent for stress in extreme fiber and 75 percent for stress in horizontal shear.

105. * * * the slope shall not be steeper than 1 in 14.

109. Maximum permissible sizes of knots are shown in the following schedule:

Nominal width of face or end (inches)	Size of knot: On narrow face within middle third of length	Size of knot: Along center line of wide face	Nominal width of face (inches)	Size of knot: On narrow face within middle third of length	Size of knot: Along center line of wide face
	Inches	*Inches*		*Inches*	*Inches*
5	1½		16	3	4¼
6	1¾		18		4½
8	2⅛	2⅜	20		4¾
10	2⅜	3	22		5
12	2⅝	3⅝	24		5⅛
14	2¾	3⅞			

109a. The size of shake shall not exceed one fourth the width of end of a green piece nor one third the width of end of a seasoned piece.

117. Wane at any point on any face shall not exceed one sixth the width of the face.

EXAMPLE 2.—SPECIFICATION REQUIREMENTS FOR JOIST AND PLANK OF Y GRADE

200. The strength ratios of this grade are 75 percent for stress in extreme fiber and 60 percent for stress in horizontal shear.

205. * * * the slope shall not be steeper than 1 in 15.

209. Maximum permissible sizes of knots and shakes are shown by the following schedule:

Size of knot: Within middle third of length: On narrow face	Size of knot: Within middle third of length: At edge of wide face	Size of knot: Along center line of wide face	Nominal width of face or end	Size of shake: In green piece	Size of shake: In seasoned piece
1	2	3	4	5	6
Inches	*Inches*	*Inches*	*Inches*	*Inches*	*Inches*
½			2	¾	⅞
¾			3	1¼	1⅜
1	½	1	4	1⅝	1⅝
	¾	1½	6		
	1⅛	2	8		
	1⅜	2½	10		
	1⅝	3	12		
	1¾	3¼	14		
	1⅞	3½	16		

216. Wane at any point on any face shall not exceed one sixth the width of the face.

EXAMPLE 3.—SPECIFICATION REQUIREMENTS FOR POSTS AND TIMBERS OF Z GRADE

The strength ratio of this grade is 60 percent for stress in compression parallel to grain.

305. * * * the slope shall not be steeper than 1 in 8 in any part of the piece.

308. Maximum permissible sizes of knots and shakes are shown in the following schedule:

Size of knot, inches	Nominal width of piece	Size of shake: In green piece	Size of shake: In seasoned piece	Size of knot, inches	Nominal width of piece	Size of shake: In green piece	Size of shake: In seasoned piece
1	2	3	4	1	2	3	4
	Inches	*Inches*	*Inches*		*Inches*	*Inches*	*Inches*
1⅝	4	2⅛	2½	4⅞	12	6¼	7½
2	5	2⅝	3⅛	5¼	14	7¼	8¾
2⅜	6	3⅛	3¾	5⅝	16	8¼	10
3¼	8	4⅛	5	5⅞	18	9⅜	11¼
4	10	5¼	6¼	6¼	20	10⅜	12½

313. Wane at any point on any face shall not exceed one fourth the width of the face.

EXAMPLE OF THE USE OF TABLES 1 TO 7 IN EVALUATING A GRADE

It is desired to find the strength ratios for a grade of joist and plank whose description accords with paragraphs 200 to 216 and provides:

a. Slope of grain not steeper than 1 in 14.

b. Wane shall not exceed one sixth the width of the face.

c. Permissible knots as given in columns 2, 4, and 6 of the following tabulation:

Nominal width of face, inches	Knots: Within middle third of length: On narrow face: Size	Knots: Within middle third of length: On narrow face: Strength ratio from table 2	Knots: Within middle third of length: At edge of wide face: Size	Knots: Within middle third of length: At edge of wide face: Strength ratio from table 4	Knots: Along center line of wide face: Size	Knots: Along center line of wide face: Strength ratio from table 3
1	2	3	4	5	6	7
	Inches	*Percent*	*Inches*	*Percent*	*Inches*	*Percent*
2	⅝	71				
3	1	68				
4	1¼	70	¾	68	1¼	70
6			1	71	2	67
8			1⅜	69	2⅝	67
10			1¾	69	3¼	68
12			2⅛	68	3¾	69
14			2⅛	70	3⅞	70
16			2½	68	4⅝	67

d. Shakes, checks, splits.

1. *Green.*—Not more than one fourth width of end.
2. *Seasoned.*—Not more than one third width of end.

Provision *a* according to table 1 corresponds to a maximum strength ratio for stress in extreme fiber in bending of 74 percent and provision *b* by table 7 gives a maximum rating of 75 percent.

The values in columns 3, 5, and 7 of the schedule of knot sizes are found from tables 2, 4, and 3, respectively, and show the strength ratios (for stress in extreme fiber) corresponding to various combinations of knot size and width of face.

Considering provisions *a*, *b*, and *c*, the grade would be rated as having a strength ratio for stress in extreme fiber in bending of about 67 percent. (It may be noted that the ratings for 4-inch and 14-inch faces under provision *c* are 70 percent, and as the provisions for slope of grain and width of wane afford ratings higher than this a purchaser who was using 4-inch by 14-inch joist of this grade could take a strength ratio for stress in extreme fiber of 70 percent.)

Provisions *d*, 1 and *d*, 2 are elvaluated by the equations at the end of table 5, sections A and B, respectively.

$$\text{For } d, 1\text{: } \frac{1}{4}=\frac{100-R}{100}, \text{ whence } R=75 \text{ percent.}$$

$$\text{For } d, 2\text{: } \frac{1}{3}=\frac{900-8R}{900}, \text{ whence } R=\frac{600}{8}=75 \text{ percent.}$$

The result of the evaluation of the grade from provisions *a*, *b*, *c*, and *d* is the finding of strength ratios of 67 percent for stress in extreme fiber in bending and 75 percent for stress in horizontal shear.

PART 3. FACTORS AFFECTING THE STRENGTH OF STRUCTURAL TIMBERS

A. QUALITY OF WOOD

The strength of the clear wood of any species varies over a considerable range and wood of the lowest quality is undesirable in a strength grade. On the other hand, recognition of the higher strength of the better wood is desirable. Inasmuch as strength is closely related to the weight or density of the wood, both of the foregoing objectives can be attained by attention to characteristics that indicate weight. The first is accomplished by excluding pieces that are obviously of exceptionally light weight and the second by using rate of growth and percentage of summer wood in grading those species in which these characteristics are acceptable criteria. Selection for rate of growth requires the number of annual rings per inch on the end of the piece to be within a specified range. Selection for density imposes in addition to limitations of rate of growth the requirement of a minimum percentage of summer wood. It is applied only to those species in which summer wood is well differentiated and is an efficient criterion of strength.

Neither of these special methods of selection greatly increases the average strength. They do, however, increase the minimum strength of accepted material of the species to which they are applicable and hence justify an increase in working stress.

B. DECAY

Ordinarily, the extent of decay is difficult to determine, no accurate estimate of its effect can be made, and its possible damaging effect and the chance of further development in service are great. Consequently decay in any form is usually prohibited in strength grades.

C. SEASONING

Tests of small specimens demonstrate that the strength of wood fibers is greatly increased by drying. In large timbers this increase is to a considerable degree offset by the checking that occurs in seasoning. Checks lessen resistance to shear and by reducing the areas acting in tension across the grain increase the effects of cross grain and of the irregularities of grain around knots. These adverse effects are less in joists and plank than in the larger pieces classified as beams and stringers or posts and timbers.

The minimum strengths in any group of larger pieces are increased so little by seasoning that beams and stringers and posts and timbers (except pieces 4 by 4 inches) are given no higher working stresses for continuously dry than for continuously wet service. The increase in strength of pieces 4 inches and less in thickness with seasoning is sufficiently great and is uniform enough that it is given recognition in working stresses for material that will be continuously dry in service.[33]

D. CROSS GRAIN

When the direction of wood fibers is not parallel to the axis of the piece longitudinal tensile and compressive stresses have components acting across the grain, in which direction wood is least strong. Cross grain is undesirable also because of the tendency of a cross-grained piece to twist with changes in moisture content. The limitations in table 1 are derived from tests on small specimens representing several species. The effect of cross grain is less on small specimens than on timbers because of the lesser development of checks in seasoning.

E. KNOTS

Knots interrupt the direction of the grain and cause localized cross grain with steep slopes.

Knots have most influence on the strength of members used in bending when they are on or near the top or bottom faces within the central portion of the length. Their effect is much less when they are near the middle of the vertical faces. Knots at or near the top or bottom faces have little influence when they are near the ends of the piece.

When a knot on the top or bottom face occupies a given proportion of the width, the strength is reduced in approximately that proportion. Hence the size of a knot is taken as its width between lines enclosing the knot and parallel to the edges of the piece. Knots on the narrow faces of joist and plank are measured only when the piece is "box heart" or is side cut with "rift grain" on the wide faces. A knot showing on the narrow face of a flat-sawn side-cut piece shows on one or both adjacent wide faces and the specified limitations to knots on wide faces of joist and plank are sufficient.

Because of the differing uses beams and stringers differ from joist and plank with respect to measurement and limitation of knots on the wide faces. In beams and stringers the smallest dimension is a simple and sufficient criterion of the effect on strength. In joist and plank a measure of the reduction of effective width of the piece is afforded by the average diameter. The permissible size of knot along the center of the wide face is determined by the effect on bending strength when the piece is used flatwise. In determining the size

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[33] See Determination of Working Stresses, p. 21.

permissible at the edge the effect when the piece is used on edge is considered and the height is assumed to be reduced by an amount equal to the size of the knot permitted at the edge of the face.

In posts and timbers the average diameter of a knot is used as the measure of the reduction in the effective cross section of the piece. The maximum size of knot permitted is the same regardless of its position in the piece.

Increase in the sizes of knots cause increased deviations in grain direction and the sizes beyond certain limits are permitted to increase only in proportion to the square root of the width of the face.

Cluster knots and knots in groups are prohibited because the sizes of the individual knots are not good measures of the deviation of grain and the resultant effect on strength.

F. SHAKES AND CHECKS

Shakes in members subjected to bending reduce the resistance to shear or the sliding of parts of the member on each other. Their effect is assumed to be approximately proportional to the reduction of shear-resisting area. In beams and stringers and in joist and plank the permitted size of shake in green material increases uniformly from zero for a strength ratio of 100 percent to one half the width of the piece for a strength ratio of 50 percent; in seasoned material the corresponding limits are one ninth and five ninths the width of the piece, respectively.

Shakes do not greatly affect the strength of members subjected to longitudinal compression. They are limited in post and timber grades primarily because of appearance and the opportunity they offer for the start of decay. The size of shake permitted in green posts and timbers increases from two tenths the width of the piece for a strength ratio of 100 percent to six tenths the width for a strength ratio of 50 percent. The corresponding limits for seasoned material are three tenths and seven tenths, respectively.

The influence of checks and splits is similar to that of shakes. Limitations of shakes, checks, and splits differ according to whether inspection is made while the timber is green or after it has seasoned. Those for the seasoned condition are necessarily the more liberal because of the formation of checks and the likelihood of extension of shakes in seasoning.

G. WANE

The schedule of permissible sizes of wane as given in table 7 has been made to conform with usual practice in grading although in some instances more strict limitations are imposed because of appearance or for other reasons. Undue importance is often attached to wane but its actual effects are much less than is implied by table 7. For example, the loss in strength due to wane one fourth the width of two adjacent faces of a beam is only about 9 percent and if such wane extended the full length of a beam the deflection of the beam under load would be only about 7 percent greater than if no wane existed. It is safe to assume that the percentage reduction in bending strength due to wane does not exceed three times the percentage reduction in area of cross section of the piece. Wane at the ends of beams is often undesirable because of the eccentric and reduced area available for bearing.

H. PITCH POCKETS

Pitch pockets ordinarliy have so little effect on timbers of structural size that they can be disregarded in grading for strength. If a number of pitch pockets are in or close to one annual growth layer a weakness in bond between growth layers is likely to exist and the piece should be carefully inspected for shakes.

I. HOLES

Holes may be caused by the dropping out of knots; by the "peck" to which some species, principally cypress, are subject; by insects and worms that attack wood; or by tools used in handling logs or timbers. The effect of knot holes or of loose or encased knots is likely to be less than that of tightly intergrown knots of the same size because of the usually lesser deviation of grain. The effect of holes from other causes is due principally to the absence of wood and the cutting across of fibers, and as such holes do not cause deviations of grain, the effect is less than that of knots of the same sizes.

TABLE 8.—*Basic stresses for clear material—not for use in design but for determining design or working stresses according to the grade of timber and the condition of exposure*

[All values are in pounds per square inch]

Species	Extreme fiber in bending	Compression perpendicular to grain	Compression parallel to grain L/d=10	Maximum horizontal shear	Modulus of elasticity
1	2	3	4	5	6
Softwoods:					
Cedar, Alaska	1,466	250	1,066	120	1,200,000
Cedar, northern and southern white	1,000	175	733	93	800,000
Cedar, Port Orford	1,466	250	1,200	120	1,200,000
Cedar, western red	1,200	200	933	106	1,000,000
Cypress, southern	1,733	300	1,466	133	1,200,000
Douglas fir, coast region	2,000	325	1,466	120	1,600,000
Douglas fir, coast region, close-grained	2,133	345	1,565	120	1,600,000
Douglas fir, Rocky Mountain region	1,466	275	1,066	113	1,200,000
Douglas fir, dense, all regions	2,333	380	1,711	140	1,600,000
Fir, commercial white	1,466	300	933	93	1,100,000
Fir, balsam	1,200	150	933	93	1,000,000
Hemlock, eastern	1,466	300	933	93	1,100,000
Hemlock, western [1]	1,733	300	1,200	100	1,400,000
Pine, western white,[2] northern white, sugar, and ponderosa	1,200	250	1,000	113	1,000,000
Pine, Norway	1,466	300	1,066	113	1,200,000
Pine, southern yellow [3]	2,000	325	1,466	146	1,600,000
Pine, southern yellow, dense	2,333	380	1,711	171	1,600,000
Redwood	1,600	250	1,333	93	1,200,000
Redwood, close-grained	1,707	267	1,422	93	1,200,000
Spruce, Engelmann	1,000	175	800	93	800,000
Spruce, red, white, and Sitka	1,466	250	1,066	113	1,200,000
Tamarack	1,600	300	1,333	126	1,300,000
Hardwoods:					
Ash, commercial white	1,866	500	1,466	167	1,500,000
Ash, black	1,333	300	866	120	1,100,000
Beech	2,000	500	1,600	167	1,600,000
Birch, sweet and yellow	2,000	500	1,600	167	1,600,000
Chestnut	1,266	300	1,066	120	1,000,000
Elm, rock	2,000	500	1,600	167	1,300,000
Elm, American and slippery [4]	1,466	250	1,066	133	1,200,000
Gum, black and red	1,466	300	1,066	133	1,200,000
Hickory, true and pecan	2,533	600	2,000	187	1,800,000
Maple, sugar and black [5]	2,000	500	1,600	167	1,600,000
Oak, commercial red and white	1,866	500	1,333	167	1,500,000
Tupelo	1,466	300	1,066	133	1,200,000

[1] Also sold as west coast hemlock.
[2] Also sold as Idaho white pine.
[3] Also sold as longleaf or shortleaf southern pine.
[4] Sold as white elm or soft elm.
[5] Sold as hard maple.

PART 4. DETERMINATION OF WORKING STRESSES

BASIC STRESSES

The values listed in table 8 afford a basis for the computation of design stresses. They are basic stresses for clear material used under such conditions of exposure that deterioration is not to be expected—for example, timbers that remain too dry to support the growth of decay. Except for stress in compression perpendicular to grain they also apply to timbers that will remain too wet for decay to attack them. They are termed basic because they are the values suggested as appropriate to pieces having a strength ratio of 100 percent.[34] They are applicable to long-time loading and inasmuch as factors of safety have been applied in their derivation they require modification only for the grade of timber used and for the conditions of exposure to which it will be subjected in service. With certain exceptions which are pointed out later, multiplication of the values in table 8 by the strength ratio or ratios of the grade gives the design stress for material that will remain either dry or saturated.

Higher initial strength than would otherwise be required is desirable in timbers exposed to decay or other deterioration in order to offset the effects of deterioration and delay replacement. It may be provided by arbitrarily increasing the size of the timbers or by using lower design stresses. The tables of stresses previously published by the Forest Products Laboratory included values for three types of exposures. Ratios among stresses for the different exposures as given in these tables varied somewhat with species but averaged approximately as indicated in table 9.

TABLE 9.—*Average ratios among stresses for different exposures*

Kind of stress	Type of exposure		
	Continuously dry or continuously submerged	Occasionally wet but quickly dried	More or less continuously damp or wet
	Percent	*Percent*	*Percent*
Stress in extreme fiber in bending	100	85	71
Stress in compression perpendicular to grain	100	70	58
Stress in compression parallel to grain	100	92	78
Stress in horizontal shear	100	100	100
Modulus of elasticity	100	100	100

The "occasionally wet but quickly dried" classification applies to timbers in outside locations but not in contact with the soil as in open deck structures of railway trestles. In such instances the material is subjected to wet or moist conditions at intervals but may be expected to dry quickly enough that the decay hazard is only moderate. The "more or less continuously damp or wet" classification covers material, such as piling, sills, or dock timbers, where wet and drier conditions alternate with the drying taking place slowly so that the average moisture condition is more favorable to decay.

[34] The values listed in table 8 are the basic stresses from which were derived the working stresses recommended in U.S. Department of Agriculture Circular 295 (*5*) and in Technical Bulletin 158 (*2*). Working stresses derived from the same basic values have also been published by the American Railway Engineering Association and the American Society for Testing Materials. Table 8 is subject to such modification as additional data and information may indicate is desirable.

Although the ratios shown in table 9 may be useful as a general guide, no simple rule for increasing the size of members or modifying design stresses can cover all conditions of use. Consequently, it may be desirable to vary considerably from these ratios. Factors to be considered include the extent to which the exposure favors decay, the expected life of the structure or part, the frequency and thoroughness of inspection, the original cost and the cost of replacements as well as the durability of the heartwood of the species and the amount of sapwood permitted. If treated timbers are used, the efficiency of the treatment and any loss of strength caused by the processes employed in preparing the material and injecting the preservative should receive attention.

Basic stresses in extreme fiber in bending, compression parallel to grain, and compression at right angles to grain are increased for "close-grain" material and for dense material. Basic stress in horizontal shear is increased for dense material but not for close grain.

Allowable stresses in extreme fiber in bending, in horizontal shear, and in compression parallel to grain are varied in accordance with strength ratio. An addition, varying in amount with the strength ratio, is made to the allowable stress in extreme fiber in bending and in compression parallel to grain for material 4 inches and less in thickness used where it will be continuously dry.

COMPUTATION OF WORKING STRESSES

Allowable working stresses for any grade can be found by the following steps:

(1) Find the strength ratio by comparing the description of the grade with the specification requirements shown in part 1 and the tables given in part 2 (see example of the use of tables 1 to 7 in evaluating a grade, p. 16); (2) multiply this ratio by the basic stress (table 8) as modified for the exposure condition except that: (3) For material 4 inches or less in thickness to be used where continuously dry, the strength ratio for stress in extreme fiber, or for stress in compression parallel to grain is first increased by one half of its excess over 50 percent. If, for example, the strength ratio for stress in extreme fiber in bending for a grade of joist and plank is 66⅔ percent, and the material is to be used where it will be continuously dry, the working stress is 75 percent of the basic stress for the species under consideration.

The application of (3) gives to dry material 4 inches or less in thickness and free from imperfections that affect strength, stresses in bending and in compression parallel to grain 25 percent in excess of those listed in columns 2 and 4 of table 8.

The strength ratio for stress in compression perpendicular to grain is 100 percent for all grades. Consequently, the allowable working stress for any grade is the basic stress (table 8) as modified for the exposure.

Working stresses in compression parallel to grain as found by the method just outlined apply to posts, columns, struts, etc., whose unsupported length does not exceed 10 times the least dimensions of the cross section. For more slender members these stresses are to be used in connection with a suitable column formula.[35]

[35] A formula recommended for use in the design of wooden columns is presented in U.S. Department of Agriculture Technical Bulletin 167 (*3*) and in publications of the American Society for Testing Materials and American Railway Engineering Association.

Recent experiments have shown that only part of the maximum end reaction produced by the loads to which a member is subjected is effective in producing horizontal shearing stress in a checked beam. Results of these experiments [36] should be taken into account in determining the effective external shear. Shear stresses 50 percent in excess of the values in column 5 of table 8 are suggested for use in designing details [37] of joints.

Tests have shown that the tensile strength of wood exceeds the modulus of rupture as found from bending tests. Hence basic stresses in tension fully equal to those listed in column 2 of table 8 are justified. However, the design load for a wooden tension member depends also on the strength of the joints through which the tensile load is transmitted to it.

Recent studies have provided data for the more exact design of joints made with bolts (*6*) and for the design of joints which utilize various types of modern connectors (*7*). The use of such connectors, which have been widely used in Europe, permits simplification of assembly and the use of preframed timbers and also in many instances results in improvement in the design and efficiency of joints. Joints can be designed for a working load as great as 75 percent or more of the tensile load proper for a member consisting of clear wood. Such a joint would, of course, carry the full load of a member whose strength was reduced to 75 percent or less of the strength of clear wood by the presence of knots or cross grain.

PART 5. STRENGTH RATIOS AND WORKING STRESSES FOR PUBLISHED GRADES

In table 10 are listed grades produced by a number of associations of lumber manufacturers whose rules describe structural grades in accordance with the principles of strength grading as presented herein. Strength ratios as found by comparing the grade descriptions with the system presented in parts 1 and 2 are shown for each grade. The working stresses recommended by the respective associations for material that will be continuously dry are also listed. These stresses agree closely with those that would be computed by the method outlined in part 4, except that the producers' recommendations for horizontal shearing stress in longleaf and shortleaf pines and Douglas fir are 10 to 30 percent higher. It should be noted in this connection that revised methods of computing effective external shear from concentrated and moving loads, as recommended in references previously cited (see footnote 36), are much more liberal than those that have been customary.

Strength ratios corresponding to the grade examples of American lumber standards and United States Department of Agriculture Circular 295 (*5*) are given in table 11.

[36] See Wood-Beam Design Method Promises Economies (*4*).
[37] For details of some types of joints see Modern Connectors for Timber Construction (*6*).

TABLE 10.—*Strength ratios for various lumber association grades—with working stresses recommended by the producers for material used where it will be continuously dry*

Name of association and effective date of grading rules	Species	Grade	Beams and stringers: Stress in extreme fiber: Strength ratio	Beams and stringers: Stress in extreme fiber: Stress [1]	Beams and stringers: Stress in horizontal shear: Strength ratio	Beams and stringers: Stress in horizontal shear: Stress [1]	Joist and plank: Stress in extreme fiber: Strength ratio	Joist and plank: Stress in extreme fiber: Stress [1]	Joist and plank: Stress in horizontal shear: Strength ratio	Joist and plank: Stress in horizontal shear: Stress [1]	Posts and timbers: Compression parallel to grain: Strength ratio	Posts and timbers: Compression parallel to grain: Stress [1]	Stress in compression perpendicular to grain	Modulus of elasticity
			Percent	*Lbs. per sq. in.*	*Percent*	*Lbs. per sq. in.*	*Percent*	*Lbs. per sq. in.*	*Percent*	*Lbs. per sq. in.*	*Percent*	*Lbs. per sq. in.*	*Lbs. per sq. in.*	*Lbs. per sq. in.*
California Redwood Association, San Francisco, Calif., Jan. 15, 1930.	Redwood	Prime structural [2]	88	1,494	88	82	83	1,707	88	82	88	1,245		
		Select structural [2]	76	1,322	75	70	67	1,280	75	70	78	1,100	267	1,200,000
		Heart structural [2]	68	1,150	60	56	57	1,024	60	56	70	1,000		
Northern Hemlock and Hardwood Manufacturers' Association, Oshkosh, Wis., Nov. 28, 1932.	Eastern hemlock	Select structural	75	1,100	75	70	67	1,100	75	70	75	700	300	1,100,000
Southern Pine Association, New Orleans, La., Sept. 1, 1932.	Longleaf pine [3]	Select structural	86	2,000	67	125	(4)	--------	(4)	--------	86	1,450		
		Prime structural	76	1,800	67	125	67	1,800	67	125	77	1,300		
		Merchantable structural.	69	1,600	67	125	65	1,600	67	125	70	1,200	380	1,600,000
		Structural square edge and sound.	69	1,600	67	125	65	1,600	56	125	70	1,200		
		No. 1 structural	60	1,400	56	105	(4)	--------	(4)	--------	60	1,000		
	Shortleaf pine [3]	Dense select structural.	86	2,000	67	125	(4)	--------	(4)	--------	86	1,450		
		Dense structural	76	1,800	67	125	69	1,800	67	125	77	1,300		
		Dense structural square edge and sound.	69	1,600	67	125	65	1,600	67	125	70	1,200	380	1,600,000
		Dense no. 1 structural [5].	--------	1,200	--------	125	57	1,200	56	125	--------	850		
Southern Cypress Manufacturers' Association, Jacksonville, Fla., May 11, 1933.	Southern cypress	Select structural	75	1,300	75	100	67	1,300	75	100	75	1,100		
		Select structural heart.	75	1,300	75	100	67	1,300	75	100	75	1,100	300	1,200,000
		Common structural	60	1,040	60	80	57	1,040	60	80	60	880		
		Common structural heart.	60	1,040	60	80	57	1,040	60	80	60	880		
West Coast Lumbermen's Association, Seattle, Wash., Aug. 30, 1932.	Douglas fir (coast region).	Select structural [2, 6]	76	1,600	75	100	69	1,600	75	120	80	1,200	345	1,600,000
		Dense select structural [6, 7].	76	1,800	75	120	69	1,800	75	140	80	1,300	380	

[1] These stresses agree closely with the values computed from the strength ratios given in the immediately preceding columns of this table and the basic stresses of table 8 by the procedure given on p. 22 except that the horizontal-shear stresses for joist and plank of select structural and dense select structural Douglas fir, structural square edge and sound longleaf pine, and dense no. 1 structural shortleaf pine are about 30 percent higher; other horizontal shear stresses for longleaf pines and Douglas fir are about 10 percent higher.

[2] Close-grain material required.

[3] Dense material required in all grades. Cluster knots and knots in groups not prohibited. Material up to 5 inches thick graded as joist and plank.

[4] Joist and plank are not described under these grade names.

[5] Admits in beams and stringers and in posts and timbers unsound knots up to 1½ inches in diameter and pin wormholes.

[6] In beams and stringers and in joists and plank knots are restricted throughout the length as required for the middle third of the length. No shakes permitted.

[7] Requires dense material.

TABLE 11.—*Strength ratios corresponding to the grade examples of American lumber standards and United States Department of Agriculture Circular 295*

Designation	Strength ratios (percent)				
	Beams and stringers		Joist and plank		Posts and timbers
	Stress in extreme fiber	Horizontal shear	Stress in extreme fiber	Horizontal shear	Compression parallel to grain
American lumber standards:					
Select	75	75	66⅔	75	75
Common	60	60	56⅔	60	60
Circular 295:					
Extra select (S1)	87½	87½			
Select (S2)	75	75			
Standard (S3)	62½	62½			
Common (S4)	50	50			

Specifications identical with the provisions of American lumber standards have been adopted by the American Society for Testing Materials and American Railway Engineering Association. Equivalent specifications have been incorporated in the standards of numerous other agencies.

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